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# GUIDE FOR AIRBORNE INFRARED ROOF MOISTURE SURVEYS

by

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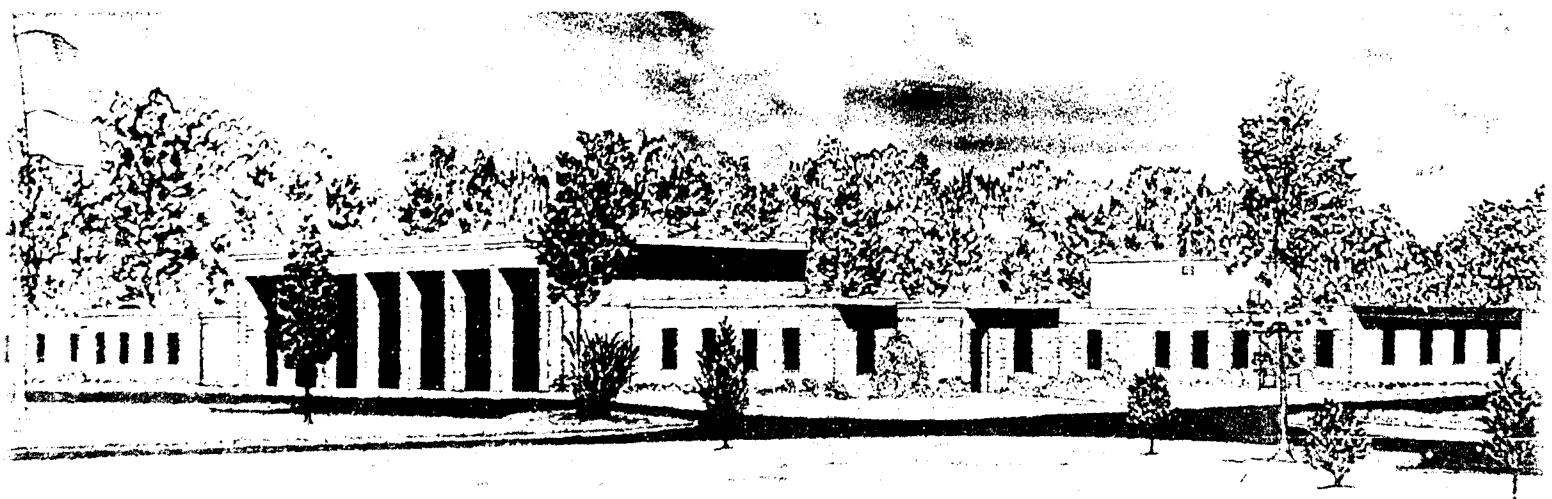

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This report presents guidance for the conduct of aerial roof moisture surveys using thermal infrared (IR) scanner systems. Specific information is presented concerning assembly of relevant data prior to the thermal IR imagery acquisition, planning the imagery mission, requesting the imagery mission, imagery interpretation, and verification of imagery derived information. In addition, numerous examples of IR imagery are included, as well as tabular listings of commercial, military, and Federal agency sources of (Continued)

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20. **ABSTRACT** (Continued).

thermal IR imagery. An example request for a thermal IR imagery mission is included in Appendix A.

# PREFACE

The work reported herein was conducted from September 1976 to June 1977 by the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, and was authorized in MIPR No. ACFM 76-4, dated 12 August 1976, from the U. S. Air Force Strategic Air Command (SAC), Offutt AFB, Nebraska, to the WES.

The study was conducted under the general supervision of Messrs. W. G. Shockley, Chief of the Mobility and Environmental Systems Laboratory, and B. O. Benn, Chief of the Environmental Systems Division, and under the direct supervision of Dr. L. E. Link, Jr., Chief of the Environmental Research Branch (ERB). Dr. Link prepared the manual. Significant contributions were also made to the content of the manual and development of the procedures presented by Messrs. C. A. Miller, A. Vazquez, C. Lebron-Rodriguez, and B. Helmuth of the ERB.

Acknowledgment is made to MAJ Richard Wyatt, Messrs. Ed Morgan and Michael Toriello, Facilities Maintenance Division, SAC, Offutt AFB, Nebraska, for excellent support during the execution of this effort. In addition, acknowledgement is made to the 155th Tactical Reconnaissance Group, Nebraska Air National Guard, Lincoln, Nebraska, for their excellent support in providing a majority of the thermal IR imagery used in this study.

Commander and Director of the WES during the conduct and preparation of this manual was COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

# GUIDE FOR AIRBORNE INFRARED ROOF MOISTURE SURVEYS

## PART I: INTRODUCTION

### General

1. This manual presents the necessary background information and procedures for planning and conducting airborne-thermal infrared (IR) roof moisture surveys. Implemented as recommended herein, the airborne IR technique is a powerful reconnaissance survey tool; however, the products of such surveys should not be considered as comparable to detailed on-the-roof inspections. As a reconnaissance tool, the IR roof survey technique provides a rapid, low-cost method to survey a large number of buildings and identify those with potential entrapped moisture problems. The exact nature and extent of those roof system problems require more detailed evaluation by on-the-roof investigations.

### Steps in Survey Procedure

2. The basic steps for conducting an airborne-thermal IR reconnaissance roof moisture survey are as follows:

   a. Assemble available data including locations of buildings with built-up roofs, buildings with internal heat sources, physical features on the roofs, and roof maintenance histories.
   b. Acquire thermal IR imagery.* This includes planning and requesting the imagery mission as well as the actual flights to acquire the imagery.
   c. Interpret the imagery to identify those roof areas suspected to have entrapped moisture.
   d. Verify information obtained from the imagery.

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* For purposes of this guide, imagery means a photographic product from an optical-mechanical scanner system.

3. The remaining portions of this manual provide details on the steps presented in the previous paragraph. Technical details on the information and techniques described in this manual were obtained from previous WES studies.*

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* Link, L. E., Jr., "Procedures for the Systematic Evaluation of Remote Sensor Performance and Quantitative Mission Planning," Technical Report M-76-8, Aug 1976, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi. Link, L. E., Jr., "Demonstration of a New Technique for Rapidly Surveying Roof Moisture," Miscellaneous Paper M-76-14, June 1976, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi. Link, L. E., Jr., "Roof Moisture Surveys at Pease AFB, New Hampshire, and Offutt AFB, Nebraska," Miscellaneous Paper M-77-2, Jan 1977, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi. Link, L. E., and Miller, C. A., "Detection of Entrapped Moisture in Roofs Using a Nuclear Moisture Meter," Miscellaneous Paper 0-75-4, Engineering and Scientific Research at WES, May 1975, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

## PART II: PRE-FLYOVER ASSEMBLY OF DATA

### General

4. The first step in the conduct of a reconnaissance roof moisture survey is to assemble available data on the roofs to be surveyed. A relatively small amount of effort at this stage can save a lot of time and effort during the later steps in the survey. In the following discussion the word anomaly is used to describe any distinct change in image tone that is readily identified from the surrounding portions of the image.

### Types of Data

5. The types of data that are important are as follows:

   a. Installation and site maps: This includes the following: a map showing the size, shape, and locations of all buildings on the installation; a site map giving the location of the installation with respect to surrounding landmarks; and the general location of the building complexes or groups of buildings to be surveyed. An example of an installation map is given in Figure 1. This type map is needed to help identify the specific buildings of interest on the thermal-IR imagery. Figure 2 gives an example of a portion of a site map showing the general layout of an installation. This map is used as an aid for navigation by the personnel flying the thermal-IR imagery mission. A 1:24,000 scale U. S. Geological Survey (USGS) quadrangle sheet is well suited for this purpose if the outline of the installation is included on the map.

   b. Buildings having built-up roofs: It is necessary to know which buildings have built-up roofs and which do not. Those buildings that do not can be eliminated from further consideration.

c. Buildings having insulated roofs: Only those buildings with built-up roofs that have insulation need be considered for the roof moisture survey.

d. Buildings having internal heat sources: Examples of such internal heat sources are boilers, incinerators, and large kitchen facilities. Such heat sources may cause warm (light tone) anomalies on the thermal-IR imagery.

e. Location and character of physical features on the roofs: Physical features such as air vents, evaporators, chimneys, drains, and expansion joints may also create warm (light tone) anomalies on thermal-IR imagery and, therefore, could be confused with areas having entrapped moisture. Knowledge of their locations will help prevent such misinterpretations. It is also important to note roofs with unique surfaces such as no gravel or with a different type of bitumen or color of gravel.

g. History of roof maintenance: It is valuable to know where patches have been made, when reroofing has been done, and which roofs are nearing their design ages. Patches may create warm anomalies on thermal imagery if the amount of bitumen used is substantially greater than that of the rest of the roof.

# PART III: ACQUIRING THE IMAGERY

## Planning the Imagery Mission

6. Information concerning roof moisture conditions can be obtained from thermal-IR imagery only if the imagery is obtained at the proper time, under favorable weather conditions, and with an acceptable sensor system. As such, it is very important to carefully plan the imagery mission. The primary questions to answer when planning a thermal-IR imagery mission are:

- a. When should the mission be flown? This includes time of year, time of day, and acceptable weather conditions.
- b. What sensor system should be used? This also includes the type of aircraft to be used and the cost of conducting the mission.
- c. How should the aircraft fly? This includes how high the aircraft should fly, and how far apart the individual flight lines should be located to obtain complete coverage.

The following paragraphs present specific guidance for answering these questions.

### Guidance for when to fly

7. Time of year: The best time to obtain thermal-IR imagery for a roof moisture survey is when the roof areas that have entrapped moisture have the greatest temperature difference from those areas that do not. When planning the mission consider the following factors:

- a. Large amounts of solar energy, as in summer, warm a roof to high temperatures and help to magnify the differences in thermal properties of wet and dry roof areas.
- b. Although solar energy is reduced in the winter months, heating of building interiors provides the necessary additional source of energy to create temperature differences between wet and dry roof areas.
- c. Buildings that are not heated can be best surveyed during summer months.

d. If thermostats are turned down in winter to conserve energy, the areas of entrapped moisture may not differ in temperature from the dry areas. Thermostats should not be turned down on the night of an IR imagery mission.

e. Roof moisture surveys should be avoided during in-between seasons when neither heating nor solar energy are emphasized. Mid-spring and mid-fall have days that should be avoided.

8. Time of day: When planning the mission consider the following factors:

a. A cool, clear night after a clear, sunny day is the best time for obtaining thermal-IR imagery for a roof moisture survey.

b. For most buildings the maximum nighttime temperature difference between wet and dry roof areas occurs between 2000 and 2300 hours. The exact time of the maximum difference is dependent on season, weather, and roof insulation types.

c. During winter months the best time for acquiring thermal-IR imagery is between 2100 and 2200 hours.

d. During summer months the best time for acquiring thermal-IR imagery is between 2200 and 2300 hours.

9. Weather conditions: When planning the mission consider the following factors:

a. IR imagery should not be obtained during or immediately after a rainfall or snowfall. It is essential that the surfaces of the roof be dry and free of standing water or accumulated snow.

b. Thermal-IR imagery should not be obtained during cloudy or warm, humid conditions. Temperature differences between wet and dry roof areas are suppressed by these conditions.

Guidance for what to fly

10. Tables 1, 2, and 3 list some commercial firms, military units, and civilian federal agencies, respectively, with the capability to acquire thermal-IR imagery. Based on performance specifications,

nearly all modern sensor systems being used by commercial firms and a majority of those in the government sector are adequate for conducting roof moisture surveys.

11. Although many aircraft-sensor combinations are acceptable for roof moisture surveys, some have distinct advantages. The following factors should be considered when planning the mission:

- a. Propellor driven aircraft such as those used by many commercial firms and the Army OV-1D Mohawk have the advantage of being able to fly lower and slower than jet aircraft.
- b. Propellor driven aircraft are normally quieter than jet aircraft. Public reaction to a low-altitude, night flight over an inhabited area is less likely to be adverse if the aircraft is quiet.
- c. Jet reconnaissance aircraft such as the RF-4C (the primary aircraft/sensor configuration used to develop the techniques presented herein) can travel long distances to the areas to be imaged and return.
- d. Imagery from the Army OV-1D Mohawk aircraft is of excellent quality but is classified, making its use for roof surveys inconvenient.
- e. Although the current thermal-IR sensor system in most RF-4C reconnaissance aircraft is not as modern as that in the OV-1D Mohawk, its imagery is not classified and it can provide adequate imagery for roof moisture surveys if flown at a height of 1000 ft above the ground. In addition, many RF-4C aircraft are presently being refitted with a modern thermal-IR sensor system that will significantly improve the imagery produced.
- f. Modern commercial thermal-IR sensors such as those produced by Bendix, Daedalus, Texas Instruments, and H. R. B. Singer can provide excellent imagery for roof moisture surveys. A comparison of commercial IR imagery and imagery obtained with the RF-4C IR sensor system at Fort Eustis, Virginia is shown in Figure 3. The commercial

imagery shown was flown at an altitude of 500 ft in a propeller driven aircraft while the RF-4C was flown at 1000 ft.

Guidance on how to fly

12. How high: Aircraft altitude (height above the ground) determines the scale of the imagery obtained with any given sensor system. For example, the AN/AAS-18 sensor system in the RF-4C Phantom aircraft produces imagery at a scale of 1:10,000 (1 in. = 833 ft) when the aircraft is flown at 1,000 ft above the ground. If the same system is flown at 2000 ft, the imagery scale is 1:20,000 (1 in. = 1667 ft). When planning the mission consider the following factors:

a. Jet aircraft such as the Air Force RF-4C should be flown at a 1000 ft minimum above ground level. Lower altitudes are not considered safe in built-up areas.

b. Imagery obtained with the AN/AAS-18 sensor system in the RF-4C aircraft from altitudes greater than 1500 ft is not adequate for roof moisture surveys because of its scale.

c. Propellor driven aircraft can be flown at a minimum of 500 ft above ground level, although 1000 ft is usually adequate.

d. Lower altitudes provide imagery that is easier to interpret (the roofs are imaged larger), but it takes more flight lines (and more film) to cover an area at low altitudes than it does at higher altitudes.

13. Flight-line spacing: When planning the mission, *it is essential that flight lines be positioned parallel to one another and close enough together to provide at least 50 percent overlap for the imagery from adjacent flight lines.* The overlap is important for two reasons. First, 50 percent overlap allows the interpreter to have two views of each building. Because of the mechanics of the scanning process, buildings on the edge of the imagery may have some roof areas that are not visible on the imagery. To prevent areas of entrapped moisture from going undetected it is essential to have two perspectives of each building so that all areas of the roofs can be surveyed. Secondly, the overlap allows stereoviewing which is valuable for interpreting the imagery. The agency

flying the mission can best position the flight lines and properly match their sensor system for the prescribed altitude or desired image scale.

## Requesting the Imagery Mission

### Military or Government agency

14. Acquiring support from a military or civil government agency requires submission of a formal request. The request must be specific on the following points:

- a. Where will the mission be flown; an outline of the area of interest should be provided on a suitable map.
- b. When will the mission be flown; time of year (month) and time of day.
- c. Acceptable or nonacceptable weather conditions.
- d. Desired aircraft altitude or image scale.
- e. Flight-line spacing to ensure 50 percent overlap.
- f. Local coordination needed and a specific point of contact.
- g. Products desired; such as negatives, positive transparencies, or prints.
- h. Specific aircraft/sensor package desired (if more than one is available).
- i. Agreement on cost of mission, if any. Table 3 presents cost data for two Federal agencies.

15. Appendix A presents an outline for preparation of mission requests and an example of a request to a military agency for a thermal-IR imagery mission. Note that it is necessary to make the request through the command headquarters flying the mission. It is advisable to send an information copy of the request to the unit that will conduct the mission if approved.

### Commercial firms

16. Support from commercial firms, such as those listed in Table 1, can be obtained by purchase order or contract procedures. The information required to implement the purchase order or contract is essentially the same as that provided to a government agency, that is, an adequate

description of the mission and desired products, see Appendix A. The mission can normally be handled using DD Form 1155 and standard purchasing procedures.

## Conduct of the Imagery Mission

### Coordination

17. Close coordination should be maintained between the installation or base personnel responsible for the roof survey and the group that will fly the imagery missions. This is primarily to insure that the mission is flown at the *proper time* and during *acceptable weather* conditions. When necessary, base inhabitants and the local civilian population should be made aware of the nighttime flights to prevent adverse reactions that may result from the surprise of a low-flying aircraft at night.

### Results of the mission

18. The main products of the mission are negatives or transparent positives and prints of the area imaged. These should be supplied to the interpreter. If negatives are used, remember that image anomalies due to entrapped moisture will appear as dark tones on the imagery, the opposite of the appearance on positive transparencies or prints. The paths of the actual flight lines flown during the mission should be plotted on a site map and provided to the interpreter.

## PART IV: IMAGERY INTERPRETATION

### General

19. Interpretation of the imagery to identify roof areas suspected of having entrapped moisture is a fairly simple and straightforward process. Tonal changes on the imagery are related to temperature changes on the features imaged. The following discussion is divided into the basic steps of the interpretation process. Examples of the types of thermal-IR imagery anomalies that can occur from internal heat sources in buildings, roof features, and entrapped moisture are presented.

### Steps in Image Interpretation

20. The recommended steps for interpreting imagery are as follows:

- a. Prepare imagery.
- b. Identify buildings with insulated built-up roofs.
- c. Examine roofs to identify anomalies.
- d. Compare anomalies to known internal heat sources and roof features.
- e. Isolate and record anomalies suspected to be caused by entrapped moisture.

#### Image preparation

21. Imagery from sensors such as the AN/AAS-18 system in the RF-4C Phantom jet is normally provided in rolls as negatives or transparent positives. For ease of interpretation, the film should be cut into strips representing individual flight lines. Figure 4 shows a portion of a strip of thermal-IR imagery at scale 1:10,000 that was produced by the Air Force AN/AAS-18 system flown at 1000 ft above the ground. For stereo viewing, adjacent image strips should be arranged so that they can be compared to the reference site map of the installation to allow identification of specific buildings. A light table will be necessary to properly view the images when transparencies are used.

22. Positive prints are also easily obtained. However, because the printing process causes some loss of detail, it is better to use negatives or positive transparencies when possible.

23. Equipment that is needed during the interpretation process should be assembled prior to interpretation. Items other than a light table that are helpful include a large magnifying glass and a pocket stereoscope (such as those used to intepret stereo aerial photographs). A magnifying glass is helpful for viewing individual roofs on the imagery. A stereoscope allows the interpreter to view a 3-dimensional scene of the roofs for those areas where overlap exists from adjacent flight line images. To view the imagery stereoscopically, it is necessary to arrange the image strips for adjacent flight lines side by side and with a separation approximately equal to the observer's eye separation. The stereoscope is then placed over the image strips so that a feature (for example, a building, road intersection, etc.) present on both image strips can be viewed through the stereoscope (that is, the feature on the image strip observed through the left lens is the same as the feature on the image strip observed through the right lens).

Identify buildings with insulated built-up roofs

24. The next step in the interpretation process is to identify those buildings with insulated built-up roofs. The imagery interpretation need only concern these buildings. Prior marking of these buildings on a reference site map speeds this process. The buildings to be included in the roof moisture survey should be marked on the imagery using a grease pencil. An effective marking is to simply draw a light circle around each building.

Examine buildings on imagery

25. The image of each insulated built-up roof should be carefully examined using the magnifying glass, or if possible the stereoscope, to identify any warm anomalies. Warm anomalies will appear as light tone against a dark background on positives (transparencies or prints) and darker tones on a light background on negatives. *Remember to examine each building from two perspectives* (i.e. on the imagery of adjacent

flight lines) *to make sure all areas of each roof have been examined.* When a number of buildings have similar roof plans, anomalies common to all of the buildings are usually due to some common feature such as vents on the roof.

Compare observed anomalies with known
<u>internal heat sources and roof features</u>

26. It is very important to note that not all warm (light tone on positives) anomalies are due to entrapped moisture, in fact, most are not. Thus, it is important to be able to determine with reasonable accuracy, those anomalies due to internal heat sources in buildings and physical features on the roofs as well as those due to entrapped moisture.

Isolate and record roof areas
<u>suspected to have entrapped moisture</u>

27. Roof areas with warm anomalies that are not recoginzed as internal heat sources or physical features on the roof can be suspected to be due to entrapped moisture. These anomalies should be recorded on a scale drawing of the roof to facilitate easy checking on the roof.

## Examples of Anomalies on Imagery

28. To effectively interpret thermal-IR imagery for roof moisture surveys the interpreter must be able to infer the cause of warm anomalies on the imagery. As stated previously, it is important to be able to recognize anomalies due to internal heat sources, physical features on the roof, and entrapped moisture. One way to gain some proficiency in recognizing the cause of anomalies is to study actual examples of those anomalies as they appear on thermal-IR imagery.

29. Examples of a variety of anomalies that occur on thermal IR imagery acquired for roof moisture surveys are presented in Figures 5 to 13. The specific features of interest on the images in each figure are summarized in the following paragraphs.

<u>Anomalies due to internal heat sources</u>

30. Large, hot equipment or machinery such as a boiler, kitchen equipment, or laundry equipment may create warm anomalies on roofs

because of their large output of heat. The excess heat may be vented from inside the building but some will probably be lost through the roof. Venting will create a warm anomaly where the warm air escapes above the roof. Loss of energy through the roof will result in higher roof temperatures and possible warm anomalies on thermal-IR imagery. Figure 5 shows a warm roof area caused by the presence of a boiler inside the building. Knowledge of such internal heat sources will prevent an anomaly such as that shown in Figure 5 from being mistaken for entrapped moisture. It is important to note that warm anomalies created by internal heat sources may mask areas of entrapped moisture. Therefore, a device such as a nuclear meter (one that does not detect entrapped moisture by temperature changes) may be desirable to survey those areas if entrapped moisture is suspected to be present.

Anomalies due to roof features

31. Many roof features produce warm anomalies on thermal-IR imagery. Fortunately, these anomalies are normally characteristic of the individual features and can be recognized. This task is made simple if some information is available concerning the location and type of features that are present on each roof.

32. Roof features that normally produce warm anomolies can be separated into the following groups:

a. Building structures on the roof.

b. Physical equipment.

c. Roof surface features.

The following papagraphs describe these features in more detail.

33. The walls of small penthouses or multi-level buildings can cause warm anomalies such as those shown in Figure 6. If they are made of heat absorbing materials such as brick, the walls can remain quite warm at night and thus, produce warm anomalies on thermal imagery. Knowledge of the boundaries of roof elevation changes and penthouse structures is very helpful for the correct interpretation of these anomalies.

34. Physical equipment on the roof such as air vents and air-conditioning evaporators can produce warm anaomalies on thermal-IR

imagery. Metal vents themselves usually appear dark (cool) on the imagery; however, if warm air is escaping from the vents, very significant warm anomalies can occur. Figures 6 through 9 show various anomalies caused by air vents. In Figure 6 the anomalies are mostly dark with minor light fringes; a situation typical of when only a small amount of hot air is escaping from the vents. Figures 7 and 8 show more obvious warm anomalies due to vents. Note the ordered pattern of the warm anomalies which helps to identify vents as the cause of the anomalies. Figure 9 shows very strong warm anomalies characteristic of a large volume of warm air coming from the vents.

35. Roof condition, changes in roof materials, expansion joints, and standing water can cause warm anomalies on thermal-IR imagery. Figure 10 shows an example of a change in roof condition. The roof labeled as new on the figure has a relatively dark uniform tone, whereas, the older roof is mottled with a more variable lighter-tone appearance.

36. Changes in roof materials such as the absence of gravel can create changes in tone such as that shown in Figure 11. Standing water can cause anomalies such as that shown in Figure 10. Notice in Figure 10 that the anomaly due to standing water is very similar in appearence to that created by entrapped moisture. Thus, it is best to obtain the imagery when little or no standing water is present on the roofs. Examples of anomalies due to expansion joints are given in Figures 7 and 8.

Anomalies due to entrapped moisture

37. Examples of warm image anomalies due to entrapped moisture are given in Figures 7, 8, 12, and 13. These anomalies range from those due to small individual areas of entrapped moisture (Figures 7 and 8) to widespread areas (Figure 12). It is evident that some of the warm image anomalies are more obvious than others. The difference in the image tone with respect to the rest of the roof of an area of entrapped moisture depends on the temperature difference between the area of entrapped moisture and the surrounding roof and the quality of the thermal-IR imagery. In general, the anomalies are more obvious on the original image negatives than on photographic prints, especially those that are enlargements such as those shown in the figures herein.

## Recording Information

38. A permanent record should be maintained for each roof (especially those determined to have entrapped moisture). Figure 13 shows a possible format. The top part of the figure is a photographic enlargement of the thermal IR image of the roof. The bottom part is a scale drawing showing anomalies on the imagery and the causes of the anomalies. Such a record would help in interpreting future thermal IR imagery of the same roof, providing a record of conditions when the imagery was obtained, and providing a mechanism to monitor expansion of entrapped moisture or effectiveness of repairs.

## PART V: VERIFICATION OF IMAGERY DERIVED INFORMATION

### General

39. Acquisition and interpretation of thermal-IR imagery as suggested in Part IV of this manual will maximize the information obtainable from the imagery. Specific roof maintenance and repair work, however, should not be based only on the results of the reconnaissance survey. Detailed on-the-roof surveys should be conducted to better determine the exact nature and extent of the roof problems identified on the thermal-IR imagery. A number of techniques are available for this task including visual inspection, nuclear moisture meters, capacitance devices, hand-held IR devices, and physical coring of the roof. It is desirable to conduct the on-the-roof surveys by a nondestructive technique, if possible, for two reasons: (a) the nondestructive technique will allow both the existence and extent of entrapped moisture to be determined, and, (b) if the suspected area does not have entrapped moisture, the roof membrane will not be penetrated. Roofs that are identified by the airborne reconnaissance survey to have potential moisture problems should be surveyed completely by some detailed on-site method. This will insure that no problem areas are overlooked and that the roof problems have been defined in a complete manner.

### Methods of Inspection

#### Visual inspection

40. Visual inspection of a roof system is an extremely valuable way to make a general assessment of roof condition. However, it is often difficult to infer conditions below the roof membrane unless core samples are taken. For the purpose of verifying roof moisture conditions on a roof, it appears advisable to supplement a visual inspection with the use of a more direct means to detect the presence of entrapped moisture.

Nuclear moisture meter

41. Conventional nuclear meters are designed to measure both moisture content and density of soil and pavement materials. Their size and weight (up to 40 pounds) are acceptable for roof moisture surveys. Details on the use of the nuclear meter as a roof survey tool were studied and are presented in a previous WES report.* The relatively low cost ($3,000 to $4,000) of the nuclear meter, the simple and reliable design, the fact that it can be used during daylight hours, and the fact that it uses a physical phenomenon different from thermal-IR imagery to detect entrapped moisture (providing an independent evaluation) are strong points in favor of its use.

Capacitance devices

42. Currently one firm, ATEC Incorporated, Madison, Wisconsin, offers roof moisture survey service with a capacitance device. The ATEC device, which is only available for use through franchised offices on a service basis, detects moisture by changes in the electrical properties of the roof system that occur with the presence of water.

Hand-held IR devices

43. Hand-held IR devices operate under the same principles as the airborne-IR devices. They provide the advantage of potentially greater temperature discrimination capability and more detailed information because of their close proximity to the roof system as it is being surveyed.

Cores

44. Perhaps the most reliable means to check an anomaly identified on IR imagery is to take a core sample in the suspected area. The core provides a direct determination, but of course, is destructive.

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* Link, L. E., and Miller, C. A., "Detection of Entrapped Moisture in Roofs Using a Nuclear Moisture Meter," Miscellaneous Paper 0-75-4, Engineering and Scientific Research at WES, May 1975, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

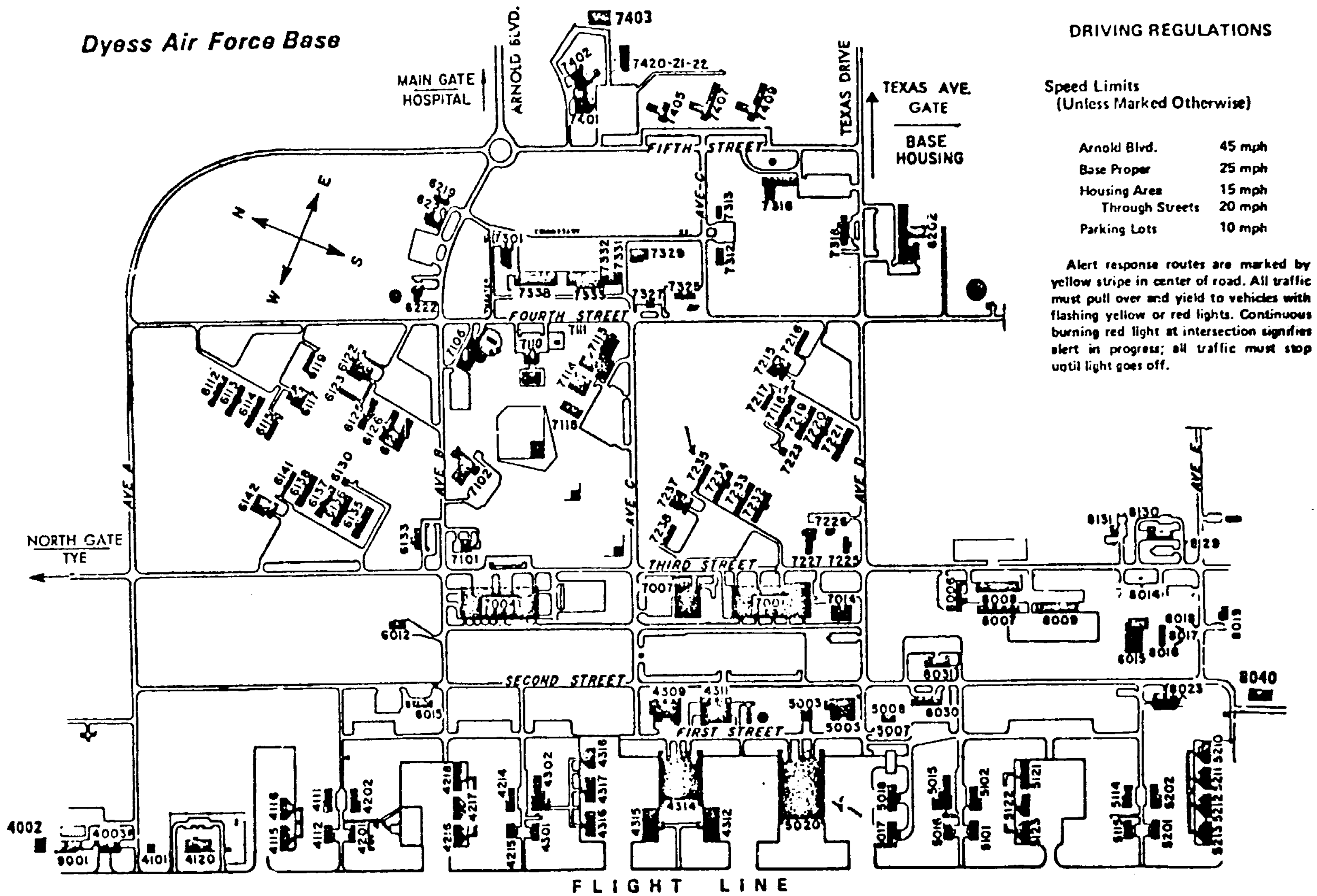



Figure 1. Installation map of Dyess AFB, Texas

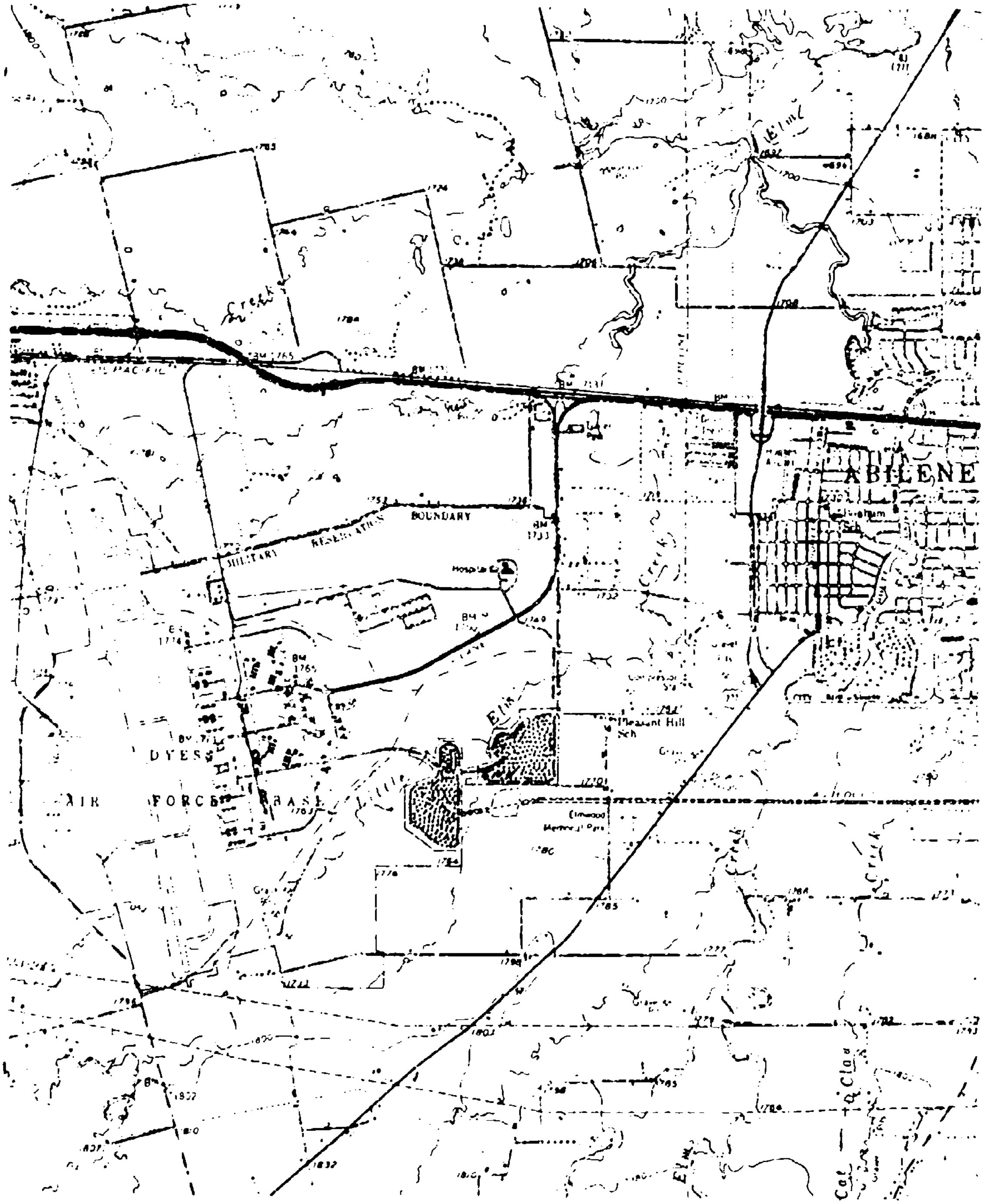
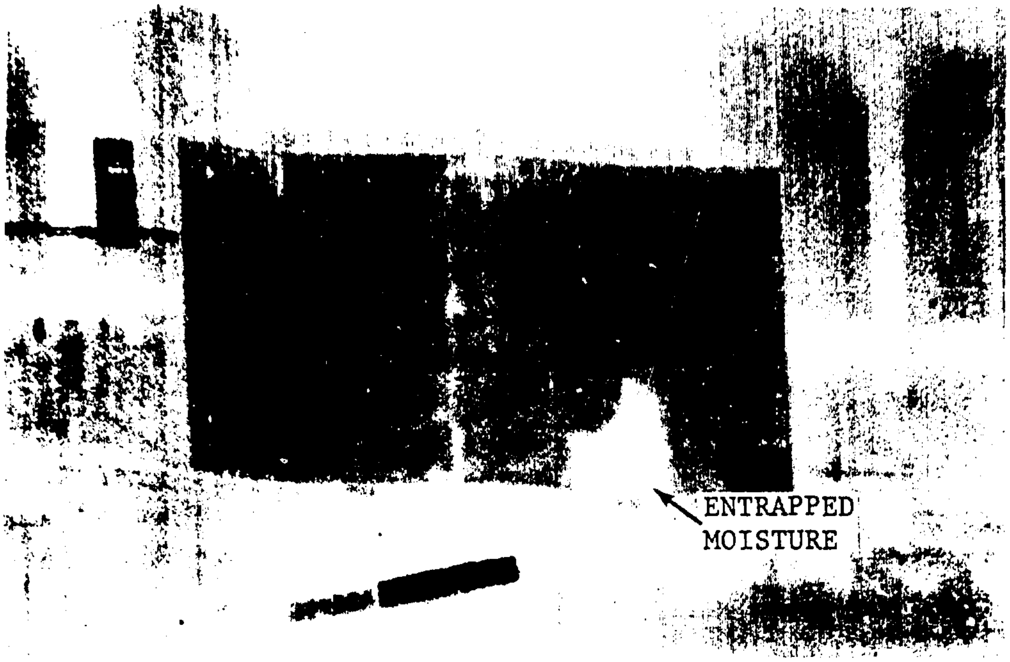
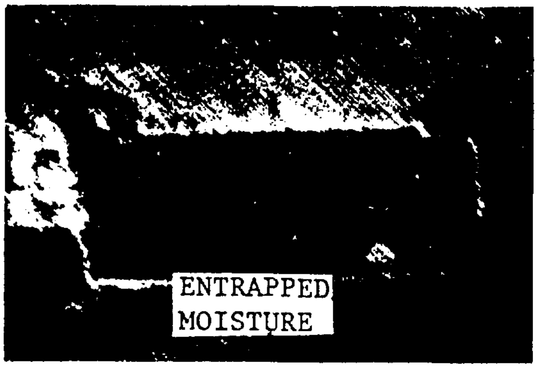



Figure 2. Portion of site map for Dyess AFB, Texas area




a. Commercial




b. RF-4C

Figure 3. Comparison of infrared images of a building obtained with commercial (a) and the Air Force RF-4C (b) scanner systems.

Figure 4. Portion of a strip of thermal IR imagery produced by U. S. Air Force AN/AAS-18 System flown at 1000 ft above the ground and at 2130 hours

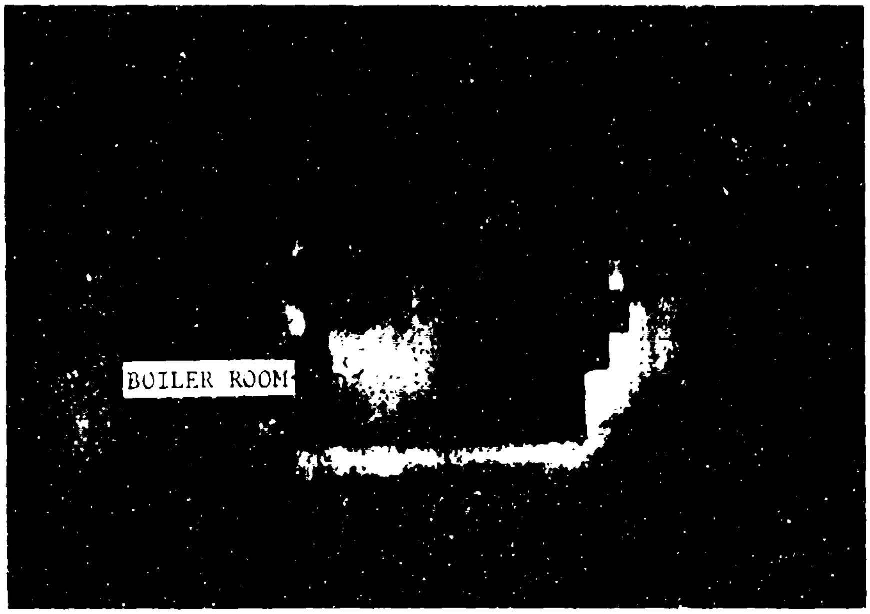



Figure 5. Thermal IR image showing warm anomaly due to internal heat source - boiler

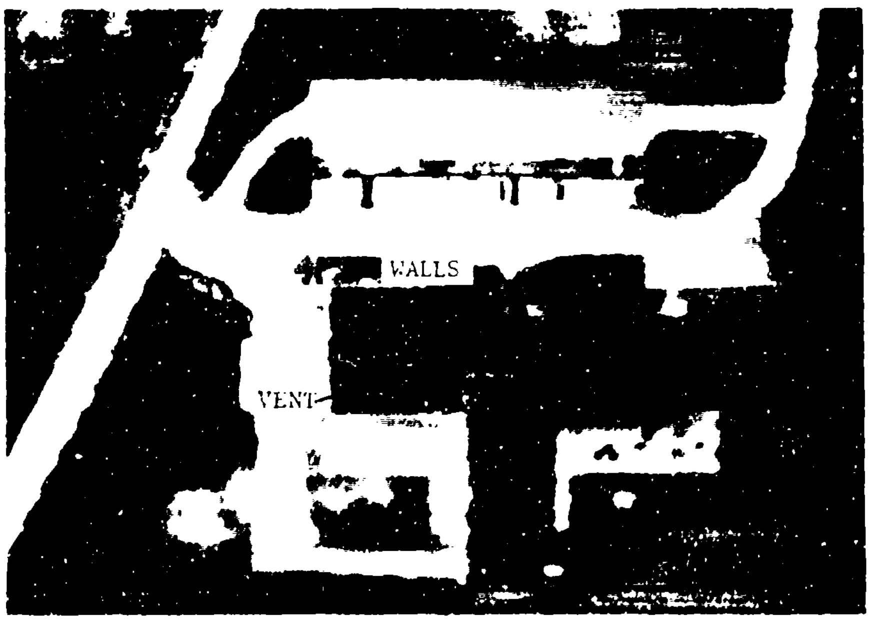



Figure 6. Thermal IR image showing warm anomalies due to vents and walls

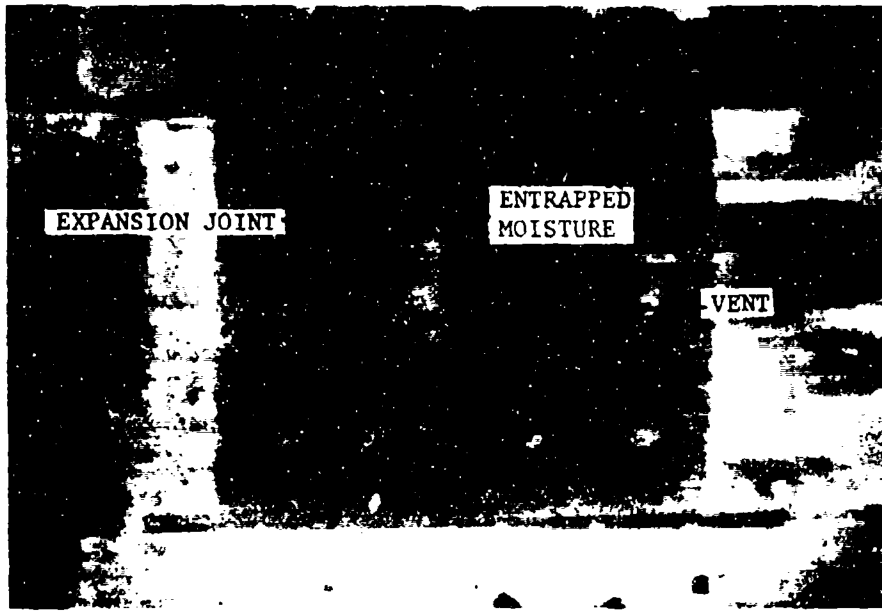



Figure 7. Thermal IR image showing warm anomalies due to vents and entrapped moisture, expansion joints appear as cool (dark) anomalies

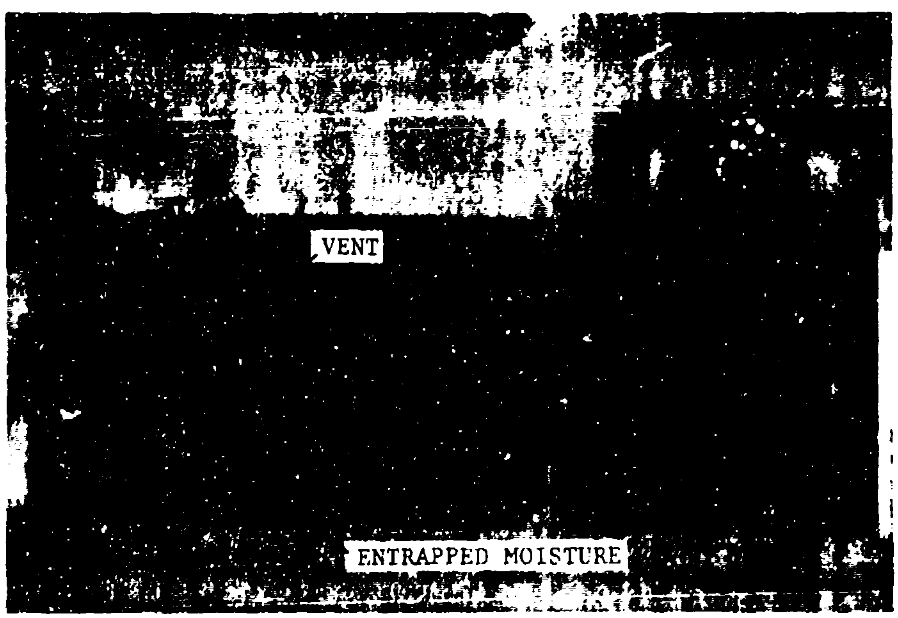



Figure 8. Thermal IR image showing warm anomalies due to vents and entrapped moisture


Figure 9. Thermal IR image showing warm anomaly due to vents


Figure 10. Thermal IR image showing tonal differences for old and new roof areas

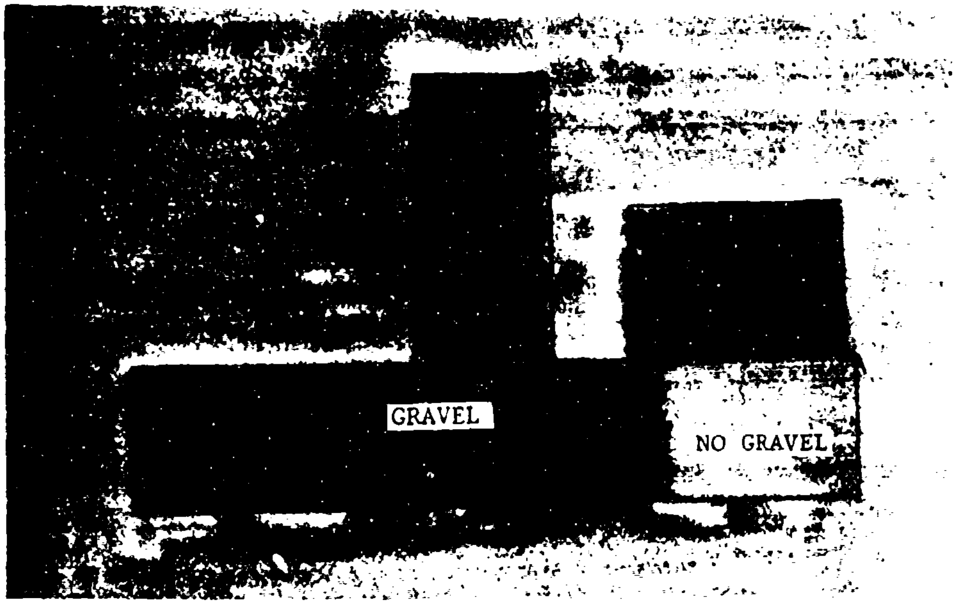



Figure 11. Thermal IR image showing tonal differences for roof areas with and without gravel

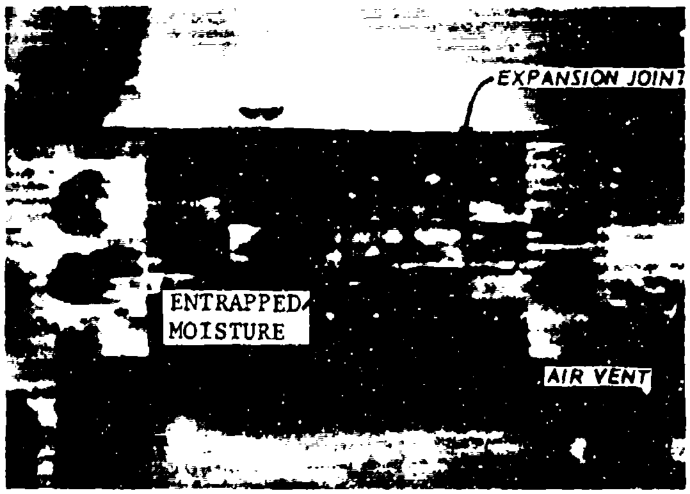
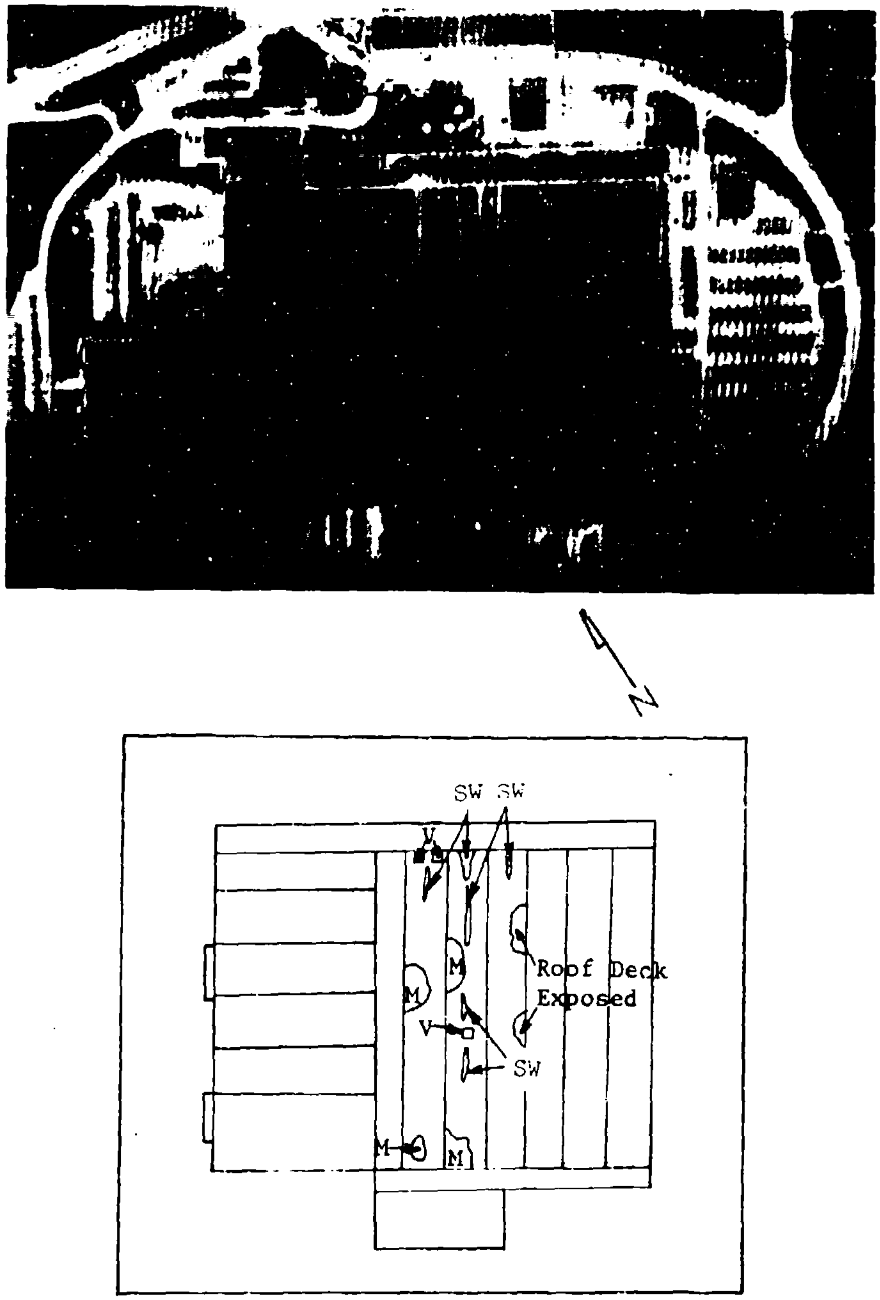



Figure 12. Thermal IR image showing warm anomalies due to vents and entrapped moisture, and cool anomaly due to expansion joints




NOTE: V = air vent.
M = entrapped moisture.
SW = standing water.

Figure 13. Suggested format for documenting roof moisture conditions

Table 1

Aerial Survey Companies Confirmed to Offer Thermal IR Survey Capabilities

| | |
|---|---|
| Mark Hurd Aerial Survey<br>Goleta, California<br>805-967-1261 | Photo Science Inc.<br>7840 Airpark Road<br>Gaithersburg, Maryland 20760<br>301-948-8550 |
| V.T.N.<br>2301 Campus Drive<br>Irvine, California 92644<br>714-833-2450 | Daedalus Enterprises, Inc.<br>P. O. Box 1869<br>Ann Arbor, Michigan 48106<br>313-769-5649 |
| Esch Tech (North American Rockwell)<br>2330 Cherry Industrial Circle<br>Long Beach, California<br>213-630-4642 | Abrams Aerial Survey Corporation<br>123 N. Larch Street<br>Lansing, Michigan 48903<br>517-372-8100 |
| Western Aerial Photos, Inc.<br>303 Convention Way, Suite 2<br>Redwood City, California 94061<br>415-369-5273 | Lockwood-Kessler-Bartlett<br>One Aerial Way<br>Syosset, L. I., New York 11791<br>516-938-0600 |
| Cartwright Aerial Surveys, Inc.<br>Executive Airport<br>Sacramento, California<br>916-422-6424 | Hunting Survey & Consultants, Ltd.<br>10 Rockefeller Plaza<br>Suite 705<br>New York, New York 10020 |
| Murray-McCormack Aerial Surveys<br>Sacramento, California<br>916-391-1651 | Kucera & Associates, Inc.<br>700 Reynolds Road<br>Mentor, Ohio 44066<br>216-255-4700 |
| MapCotec, Inc.<br>P. O. Box 5267<br>Daytona Beach, Florida 32020 | Air Survey Corporation<br>Newton Square South<br>Reston, Virginia<br>703-471-4510 |
| Chicago Aerial Survey<br>2140 Wolf Road<br>Des Plaine, Illinois 60018<br>312-298-1480 | Legislative Council of Photogrammetry (2)<br>1001 Connecticut Ave., N. W.<br>Suite 800<br>Washington, D. C. 20036<br>202-452-1527 |
| Aerial Service, Inc.<br>Cedar Falls, Iowa<br>319-266-6181 | |

Table 2

Military Sources of Thermal IR Imagery

## U. S. Air Force

U. S. Air Force Tactical Air Command
Directorate DOOR
Langley Air Force Base, VA 23665

U. S. Air Force Tactical Air Command
363rd Tactical Reconnaissance Wing
Shaw Air Force Base, SC 29152

U. S. Air Force Tactical Air Command
67th Tactical Reconnaissance Wing
Bergstrom Air Force Base, TX 78743

## U. S. Air National Guard

Alabama Air National Guard
187 Tactical Reconnaissance Group
Donnelly Field
Montgomery, AL 36105

Alabama Air National Guard
117th Tactical Reconnaissance Wing
Municipal Airport
Birmingham, AL 35217

Nebraska Air National Guard
155th Tactical Reconnaissance Group
Lincoln Municipal Airport
Lincoln, NE 68524

## U. S. Army

U. S. Army III Corps
131st Military Intelligence Co.
Aerial Surveillance-AF2F-DPT-OP
Fort Hood, TX 76544

U. S. Army Electronics Proving Ground
ATTN: STEEP-APF
Fort Huachuca, AZ 85613

## U. S. Army National Guard

Georgia Army National Guard
Building 747
Dobbins Air Force Base
Marietta, GA 30060

Army Aviation Support Facility
1921 Turner Road, S.E.
Salem, OR 97302

## U. S. Navy

Reconnaissance Attack Wing I
Naval Air Station
Key West, FL 33040

Marine Tactical Reconnaissance
Squadron 3
Marine Aircraft Group
3rd Marine Aircraft Wing, FMFPAC
El Toro, MCAS
Santa Ana, CA 92709

Table 3

Federal Agencies With Thermal IR Scanner Equipped Aircraft

| | Agency/Organization | Approximate Costs | Send Requests To: |
|---|---|---|---|
| 1. | U. S. Dept. of Agriculture/<br>U. S. Dept. of Interior<br>Interagency Fire Center | $125 to $145 per hour for aircraft and sensors | Mr. Robert Bjornsen<br>Fire Management<br>Interagency Fire Center<br>3905 Vista Avenue<br>Boise, ID 83705 |
| 2. | U. S. Energy Research and Development Agency<br>Division of Safety, Standards, and Compliance | Not Available | Mr. L. Joe Deal<br>Assistant Director for Health Protection<br>Division of Safety, Standards, and Compliance<br>U. S. ERDA<br>Washington, DC 20545 |
| 3. | Environmental Protection Agency<br>National Environmental Research Center<br>Environmental Monitoring and Support Laboratory<br>Remote Sensing Division | Not Available | Mr. Albert Pressman<br>Deputy Director<br>Remote Sensing Division<br>Environmental Monitoring and Support Laboratory<br>P. O. Box 15027<br>Las Vegas, NV 89114 |
| 4. | U. S. Geological Survey<br>Airborne Operations, Petrophysics, and Remote Sensing Branch | Not Available | Mr. Rutledge Mills<br>Chief, Airborne Operations, Petrophysics, and Remote Sensing Branch<br>Mail Stop 964<br>Box 25046<br>Denver Federal Center<br>Denver, CO 80225 |

(Continued)

Table 3 (Concluded)

| Agency/Organization | Approximate Costs | Send Requests To: |
|---|---|---|
| 5. National Aeronautics and Space Administration (NASA)<br>Ames Research Center | Not Available | NASA/Ames Research Center<br>Airborne Applications Support<br>Program Office<br>Code SP-240-5<br>Moffett Field, CA 94035 |
| NASA<br>Earth Resources Laboratory | Not Available | Mr. Wayne Mooneyham<br>Director<br>Earth Resources Laboratory<br>1010 Gause Road<br>Slidell, LA 70458 |
| 6. Tennessee Valley Authority (TVA)<br>Maps and Surveys Branch<br>Imagery Acquisition Unit | $375 per day base charge plus $100 per flying hour | Mr. William S. Massa<br>Chief Maps and Surveys Branch<br>TVA<br>200 Haney Building<br>Chattanooga, TN 37401 |

# APPENDIX A: RECONNAISSANCE REQUEST PROCEDURES FOR GOVERNMENT/MILITARY AGENCIES

1. The following outline should be followed when preparing a request for a reconnaissance mission:

a. Subject. Air Reconnaissance Request

b. To. Fill in address of agency to which request is being made. The headquarters of an agency should be used if applicable. For example, a request for a mission by the 363d Tactical Reconnaissance Wing (TRW), Shaw AFB, South Carolina, should be made to Headquarters, Tactical Air Command, Langley AFB, Virginia, with an information copy to the 363d TRW.

c. Type of request.

(1) Type of mission--specify imagery mission.

(2) Type of coverage--specify area coverage.

(3) Sensor--specify thermal infrared sensor.

(4) Aircraft--specify aircraft desired.

d. Area of interest.

(1) Include map with area of interest clearly outlined, if not possible include corner coordinates of area of interest and map series, sheet number, and edition of applicable map. It is strongly recommended that a map be sent with the request for most expedient execution of the mission.

(2) Describe target area verbally.

e. Purpose of request and results desired.

(1) Present the reason for flying the mission such as "roof moisture reconnaissance survey."

(2) Clearly outline products desired. For example, "one set of duplicate negatives, and two sets of positive prints of entire area of interest are needed."

f. Special instructions.

(1) Desired scale or altitude (distance of aircraft above ground level).

(2) Desired time for flight including time of year and time of day.

(3) Acceptable weather conditions.

(4) Flight-line spacing--normally specify 50 percent overlap for adjacent flight lines.

g. <u>Delivery date/address/point of contact</u>. Specify desired delivery date, address for delivery, and a point of contact for the project.

h. <u>Copy furnished</u>. Furnish a copy of the request to interested or involved parties. For example, if request is made to Headquarters, Tactical Air Command for a mission to be flown by the 363d TRW, Shaw AFB, a copy of the request should be furnished to the 363d TRW.

2. The following is an example of a request following the outline given in the previous paragraph:

"SUBJECT: Air Reconnaissance Request

Commander
Department of the Air Force
U. S. Air Force Tactical Air Command
ATTN: DOOR
Langley Air Force Base, Virginia, 23665

1. It is requested that the 67th TRW, Bergstrom Air Force Base, Texas, acquire the thermal-IR imagery to supply necessary information for a roof moisture reconnaissance study of Dyess AFB.

2. Thermal-IR imagery using the AN/AAS-18 system obtained at an aircraft (RF-4C) altitude of 1000 ft above ground level is desired. The area of interest is the Cantonment area of the base where all major buildings are located. A standard USGS Quadrangle Map (1:24,000 scale) is inclosed (Incl 1) showing the area oulined in black. The imagery should be obtained on a cloud free night following a clear, sunny day. The roofs should have no standing water present on them. A image scale of 1:10,000 with a 50 percent overlap of adjacent flight lines is desired. One copy duplicate negatives and one copy of positive transparencies are desired for the entire area of interest. The mission is desired during the month of June and should be flown between 2100 and 2300 hrs local time. The imagery products are needed by mid-August and should be sent to:

Commanding Officer
Dyess Air Force Base
ATTN: Base Civil Engineer
Dyess AFB, Texas 79607

3. If you have any further questions concerning this mission, please contact Mr. A. A. Smith at telephone No. 601-636-3111, extension 1111.

CF: U. S. Air Force Tactical Air Command
67th Tactical Reconnaissance Wing
ATTN: DOO
Bergstrom Air Force Base, Tex. 78743

**In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.**


Link, Lewis E

Guide for airborne infrared roof moisture surveys / by L. E. Link, Jr. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.

29, [4], 3 p. : ill. ; 27 cm. (Instruction report - U. S. Army Engineer Waterways Experiment Station ; M-78-1)

Prepared for U. S. Air Force Strategic Air Command, Offutt Air Force Base, Omaha, Nebraska.

Includes bibliographical references.

1. Aerial survey. 2. Infrared rays. 3. Moisture. 4. Roofs. I. United States. Air Force. Strategic Air Command. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Instruction report ; M-78-1.

TA7.W34i no.M-78-1